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13. ABSTRACT

The overall objective of the research was to set up facilities to generate transient magnetic fields in the megagauss range. The principal application envisaged was the eventual combination of megagauss targets with high energy accelerator beams to test fundamental features of quantum electrodynamics. Both of these objectives were met within the duration of the grant. This report summarizes the principal results of the research.

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GENERATION OF ULTRA-HIGH MAGNETIC FIELDS

FINAL REPORT

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AROD Projects Number DA-ARO-D-31-124-G611 and DA-ARO-D-31-124-70-G31.

1 November 1964 - 30 November 1971.

0. ABSTRACT

Support was provided by the U.S. Army Research Office, Durham, with the overall objective of enabling our laboratory to set up facilities to generate transient magnetic fields in the megagauss range. The principal application envisaged was the eventual combination of megagauss targets with high energy accelerator beams to test fundamental features of quantum electrodynamics. Both of these objectives were met within the duration of the grant. Our Laboratory has built the following megagauss generators:

Device	Peak Fields Attained
Pulsed coil devices	2.2 MG
Electromagnetic implosion (Cnare effect) devices	1.6 MG
High explosive generators	4.2 MG

An experimental series designed to test radiation reaction and quantum effects in magnetic Bremsstrahlung was carried out with complete success at the Stanford Linear Accelerator Center during the period June - November 1970.

1. SUMMARY OF PRINCIPAL RESEARCH RESULTS

(All references are collected in the Bibliography, Section 3: The reference code [6a] for example, means paper #6 listed in Section 3a).

(a) Flux Compression (Experimental):

(i) Explosive Flux Compression. - A total of approximately 28 complete megagauss experiments in which the fields were generated by means of explosively driven devices, were conducted during the period 1967 - 70. Two

principal types of generators were developed: 1) Cylindrical ("doughnut") devices employing 24 SE-1 detonators and composition B and PBX explosive lenses weighing approximately 11 lbs. These devices were fired in conjunction with a 30 kJ seed field bank, and peak fields of the order of 1 MG were measured. An exceptional feature of the IIT experiments is that excellent cylindricity of the implosions were achieved and documented with framing camera records. This work is described in [1c], [2c], [6c], [31a], [5b], [6b]. 2) Cylindrical (Top Hat) compression devices employing only one SE-1 detonator and about one pound of "Detasheet" explosive. Peak fields of 4.2 MG were recorded with these devices. See [12a], [31a], [17b] and [6c].

(ii) Electromagnetic Flux Compression (Cnare Effect). - Extensive parameter studies were carried out in order to determine empirical optimizing ranges for the EMC technique. The performance of these devices turned out to be unexpectedly sensitive to variations in the ratio of the height of the primary coil to the height of the Cnare foil, as well as the mechanical temper of the Cnare foil. Peak fields of the order of 1.6 MG were generated with a 60 kJ capacitor bank. See [17a], [31a], [9b], [16b], [5c].

(b) Flux Compression (Theoretical):

Extensive studies were undertaken to clarify the operation of megagauss devices, to discover optimizing techniques and to extract solid state physics information on matter under extreme conditions. In particular, we examined the magnetic field injection mechanism in flux compression devices [2a], [12a], [22a], [7b], [2c]; start-up, take-over, and intermediate field flux compression [12a], [14a], [15a], [19a], [20a], [22a], [25a], [30a], [31a], [2b], [11b], [15b], [17b], [5c], [6c]; the conditions associated with the terminal or "turn-around" stage of flux compression were studied in [14a], [17a], [20a], [25a], [12b], [5c] and [6c]. Techniques for data reversion were developed which permit one to infer the resistivities and energy transfer efficiencies of the liners during the implosion phase [14a], [20a], [30a], [31a]. Analysis of the results from a wide variety of implosion devices indicates that the resistivities of the liner materials under megagauss conditions remain at relatively low values.

(c) Applications to Quantum Electrodynamics:

(i) Theoretical Studies. - The range of possibilities for quantum electrodynamics experiments accessible with the combination of megagauss targets and high energy accelerator beams was studied in [1a]. This survey indicated that the most promising line of investigation involved magnetic Bremsstrahlung [9a], [1b], [18b].

(ii) Megagauss Bremsstrahlung Experiment at Stanford Linear Accelerator Center. - A specific proposal to measure magnetic Bremsstrahlung in the 20 GeV beam of the Stanford Linear Accelerator Center was presented in [9a] and an experiment was designed. Megagauss targets utilizing pulsed coils and Cnare implosions were both successfully tried during the course of the SLAC program. A total of 15 complete megagauss-accelerator experiments were carried out. Sometimes as many as 4 MG shots, including both coil and implosion configurations, were completed in a single day. Preliminary results of the experimental series at SLAC were reported in [23a], [24a], [20b], [22b].

The final results are collected in [32a], [7c], [8c]. Analysis of the results indicates that the Bremsstrahlung spectrum agrees with theoretical predictions. The absolute radiation rate expected is also within the limits of experimental error. However, the observed electron deflections are consistently higher by about 10% than the calculated values. This last point is still undergoing critical analysis and subsidiary experimental checks.

(d) Megagauss Fields Produced with Coils:

A capacitor bank termination adaptable to coils was originally built for the Stanford experiment in order to provide a back-up of reliable medium intensity fields of circa 0.7 MG. However, the coils that were designed proved to be better by factors of 2 and 3, so that peak fields of 2.2 MG could be reliably and repeatedly generated. These coils exploded concentrically with negligible damage to devices placed in the interior field region; so, for example, emulsion pellicles and delicate field probes survived MG coil shots. These coil generators are now being adapted for solid state physics experiments. (Magneto-reflectance of laser beams [Prof. J. Davis, private communication]). [13a], [22a], [24a], [32a], [19b], [21b], [7c], [9c].

(e) Hysteresis and Fatigue:

An auxiliary program of research concerned with hysteresis and fatigue in magnetic cooperative systems, structures, and materials has also been carried out. A new general criterion for the shake-down of structures has been developed and checked against know results in structural engineering. Furthermore, a general theory of hysteresis has been developed. Applications to metal fatigue are now being studied. [4a], [5a], [6a], [18a], [21a], [26a], [27a], [28a], [29a], [3b], [8b], [10b], [14b], [1c], [3c].

2. CONSTRUCTION OF LABORATORY FACILITIES

It was pointed out in the original proposal to AROD that a research program of this magnitude could not be organized around a few specific experiments, but rather that an entire range of facilities adequate for carrying out studies of flux compression was absolute essential. Accordingly, special laboratory facilities were constructed at the IIT campus for carrying out all "indoor" experiments --- specifically megagauss shots involving coils for electromagnetic implosion generators. The "outdoor" experiments which necessitated the detonation of high explosive devices were conducted at a special bunker complex built at the IITRI firing range at La Porte, Indiana. These facilities are among the most sophisticated of their kind available at any university laboratory in the United States. [3a], [31a], [4b], [5b], [6b], [1c], [2c], [5c], [6c].

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